Prepared in cooperation with the Sweetwater Authority

Determining Age and Vertical Contribution of Ground Water Pumped from Wells in a Small Coastal River Basin

A Case Study in the Sweetwater River Valley, San Diego County, California

ABSTRACT

The age and vertical contribution of ground water flowing into four municipal supply wells were determined under pumping conditions in order to better understand the source of water to the wells. Vertical flowrate inside the wells, located in the Sweetwater River drainage basin of San Diego County, California, was measured at selected depths using a dye-injection technique. Flowmeter results indicate that as much as about half the pumped water comes from the alluvial deposits and half from the underlying San Diego Formation. Chemical analysis of water samples collected at specific depths support this vertical distribution of pumped water. Tritium and carbon-14 data indicate that ground water from the alluvial deposits was recharged less than 50 years ago, and ground water from the San Diego Formation is thousands of years old, some as much as 16,000 years old.

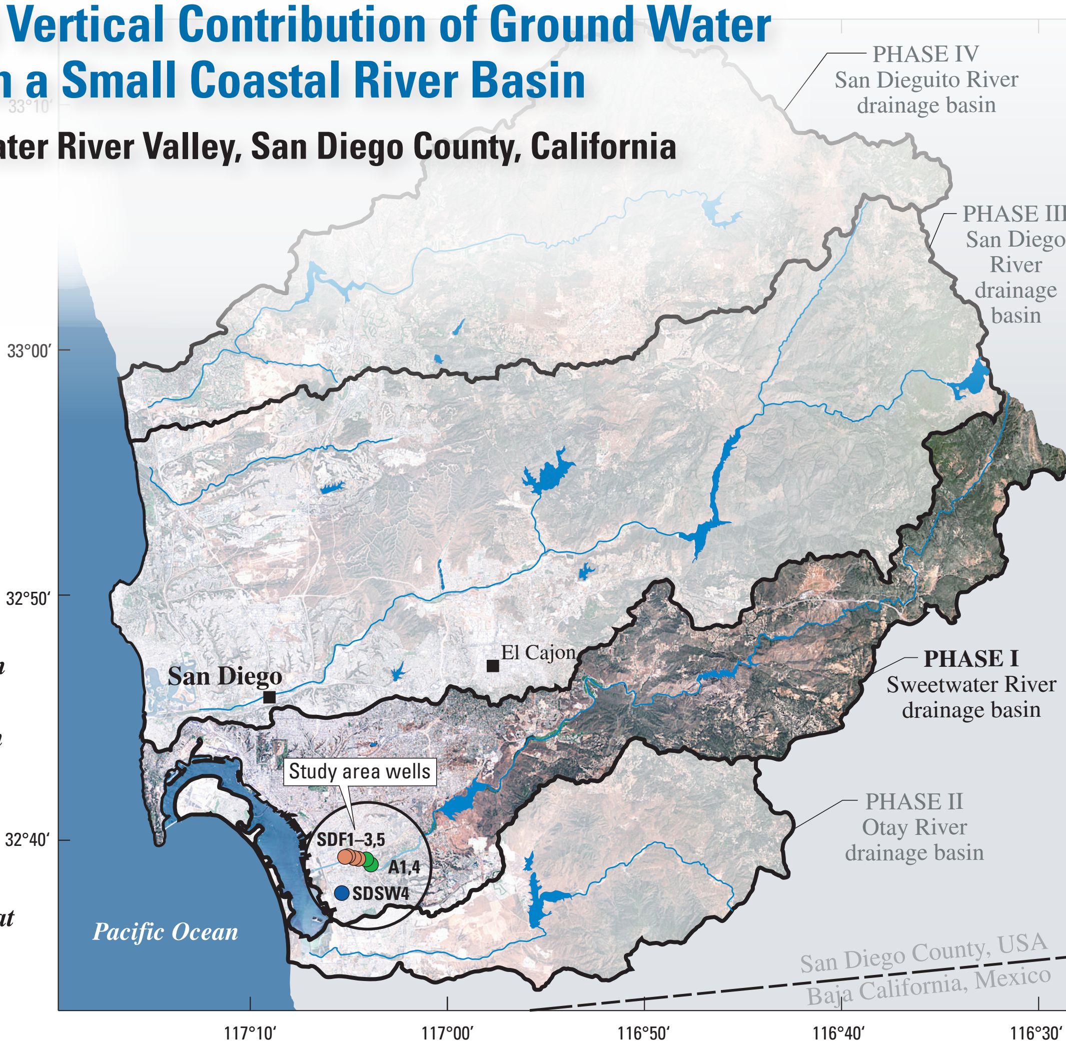

Figure 1. Location of wells sampled to determine the age and vertical contribution of ground water pumped from four municipal supply wells (SDF1–3, 5). This analysis is part of a USGS regional assessment of ground-water resources in the San Diego area.

Study Area

The U.S. Geological Survey is assessing regional ground-water resources in the San Diego area (*fig. 1*). Phase I of that assessment focuses on the Sweetwater River drainage basin. This report describes results from an initial part of that assessment.

The Sweetwater Authority, a local retailer in the San Diego area, provides water from four municipal supply wells in the Sweetwater River channel (*figs. 1 and 2*; URS Greiner Woodward Clyde, 2000). These wells were designed to extract ground water from the San Diego Formation, which underlies alluvial deposits in the river channel (Boyle Engineering Corporation, 1994, 1999).

The alluvial deposits are composed of sand, silt, and cobbles, and are estimated to be as much as 250 ft thick. The San Diego Formation is composed of similarly coarse sediment deposited during the Pliocene about 1 million years ago, is as much as 1,200 ft thick, and is believed to be the primary aquifer in the coastal San Diego area (California Division of Mines and Geology, 2001).

Figure 2. Sweetwater River channel showing one of four municipal supply wells that was sampled.

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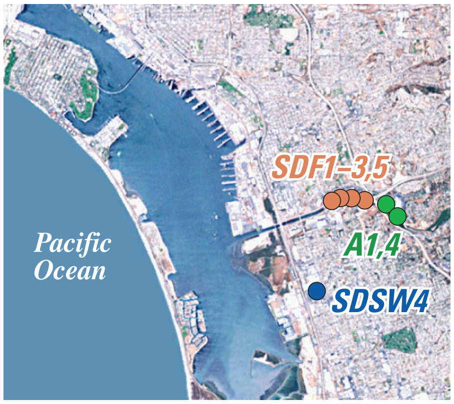

Figure 3. Shallow alluvial (A1 and A4) and deep (SDSW4) monitoring wells form geologic and chemical end members. Municipal supply wells (SDF1, 2, 3, and 5), which were measured for flow and sampled for water quality, extract water from the alluvial deposits and (or) the underlying San Diego Formation.

The location of the contact between the alluvial deposits and the San Diego Formation is uncertain, and it is not known how much water is contributed to the supply wells from each formation. The source of the pumped water is of interest to the Sweetwater Authority because water pumped from shallow alluvial deposits probably was recharged more recently and may require more treatment than older ground water pumped from the deeper San Diego Formation. In general, ground water recharged less than 50 years ago is more susceptible to anthropogenic contamination.

Methods of Investigation

Understanding water from a municipal supply well requires analyzing the well while it is pumping, specifically,

1. Measuring where water flows into the well, then
2. Sampling water from different depths within the well.

In addition to depth-dependent water samples collected from four municipal supply wells, water samples were collected from shallow and deep monitoring wells (*fig. 3*).

Our hypothesis is that water from the shallow (A1, A4) and deep (SDSW4) monitoring wells is chemically different and forms chemical end members. These end members indicate that ground water from the alluvial deposits is different than ground water from the underlying San Diego Formation. This difference can be used to determine how much water is contributed to each municipal supply well by the alluvial deposits and how much by the San Diego Formation.

Water samples were collected at different depths within each municipal supply well (SDF1–3, 5) and analyzed. Equipment used to sample the supply wells is shown in *figure 4*. Well construction and sample depths are shown in *figure 5*.

Measuring flow into a well

Measuring flow into a well can be done in several ways. A primary consideration, however, is being able to lower the measuring device down inside the well, while the well is pumping. Commonly, less than one inch of space is available between the pump and the well casing. For this reason, a narrow 1/2-inch-diameter hose is used to inject rhodamine dye at specific depths. Then the dye concentration is measured in water discharged from the well using a flourimeter (*fig. 4*).

The arrival time of the dye indicates the velocity of the water inside the well. Rate of flow into the well at specific depths can be calculated from depth of injection, dye velocity, geometry of the well casing and pump, and total discharge from the well (Izbicki and others, 1999). Results, expressed as a percentage of total discharge from each municipal supply well, are shown in *figure 5*.

Sampling water from a well

After flow into a well has been measured, the vertical distribution of flow is analyzed and strategic sample depths are chosen (Izbicki and others, 1999). The goal is to characterize differences in water quality with depth. Because of the relatively high cost of chemical analysis, a balance needs to be achieved between the number of samples and the resolution of vertical changes in water quality. In this study, six samples per well were found to be a cost-effective number (*fig. 5*). Each sample from selected depths is collected using a small-diameter hose similar to that used to inject the dye and measure flow rate (*fig. 4*).

Analysis of Flow Data

Flow into the municipal supply wells is shown in *figure 5*. As illustrated by SDF2, water can flow into a well through nearly all perforated intervals, creating a fairly uniform vertical distribution of inflow. Or, as illustrated by SDF3, water may flow into a well through only a few perforated intervals, creating a focused depth of inflow. The relative percentage of total discharge contributed from different depths helps scientists interpret the hydraulic and depositional characteristics of geologic deposits adjacent to the well.

Analysis of flow data for the municipal supply wells shows that more water is contributed to each well from shallow depths. This finding is typical of geologic settings where shallow deposits are younger and less compacted, and thus yield water more readily. Flowmeter data depicted in *figure 5* indicates that the percentage extraction from shallow water in alluvial deposits ranges from 0% (SDF1) to 65% (SDF3) (*table 1*).

Analysis of Chemical Data

Chemical data were collected from shallow and deep monitoring wells in order to create a mixing line between the two water types (end members). This concept is illustrated in *figure 6*. As hypothesized, water from the shallow wells (A1 and A4) is different from water from the deep well (SDSW4). Water from different depths within the four municipal supply wells generally falls along this alluvial mixing line. A second mixing line between water from the deep well and seawater was created to determine if water from the shallow or municipal supply wells contains recent seawater.

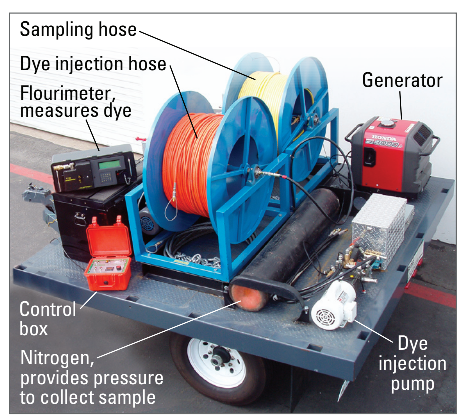

Figure 4. Equipment used to measure rate of water flowing into a pumping well and to sample water chemistry at selected depths. Photo by Allen Christensen, U.S. Geological Survey.

General Chemistry

Nearly all water samples collected from the shallow, deep, and municipal supply wells have a similar major-ion chemistry. Therefore, it is not possible to use major ions to differentiate water samples collected at different depths. The dominant major ions found in all samples are calcium, magnesium, bicarbonate, and chloride, and the general water type is calcium bicarbonate. Total dissolved solids range from about 1,400 to about 2,800 mg/L (*table 1*), indicating that the water is much more saline than precipitation (several mg/L), but not as saline as seawater (35,000 mg/L).

Chloride-Boron Ratio

The ratio of chloride to boron is useful in discriminating among the many water samples. Water from the shallow wells has less boron and more chloride than water from the deep well. This difference implies that the shallow wells have a different source of water than the deep well. Data from the municipal supply wells fall generally along the alluvial mixing line (*fig. 6*), indicating water pumped from the wells is a mixture of shallow and deep ground water. That data from the supply wells do not fall along the seawater mixing line indicates that the supply wells do not pump a significant amount of seawater from shallow depths, despite elevated dissolved-solids concentrations.

Water sampled from municipal supply well SDF2 shows a progression of water chemistry spanning most of the range from deep to shallow water. Generally, the concentration of chloride in water from SDF2 increased gradually as the depth of the water sampled decreased (*fig. 6*). This result can be predicted from measurements of flow into the well (*fig. 5*) because the well produces a nearly equivalent amount of water from each depth. In contrast, all samples from SDF3 plot in nearly a single place on the alluvial mixing line. This too is predictable because the well produces nearly all of its water from essentially a single depth (200 ft). Chloride-boron data for SDF1 and SDF5 produce similarly predictable patterns based on flowmeter results. Analysis of chloride-bromide and chloride-iodide ratios produced the same conclusions as analysis of chloride-boron ratios.

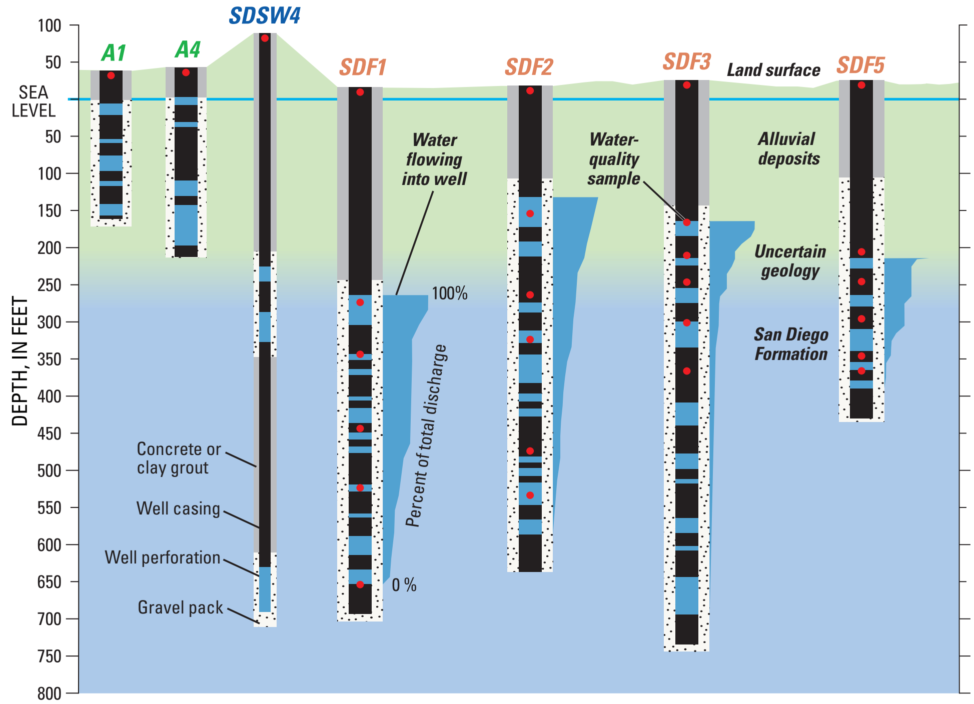

Figure 5. Construction, measured flow into municipal supply wells, and water-quality sample depths for alluvial (A1, A4), deep (SDSW4), and municipal supply wells (SDF1, 2, 3, and 5).

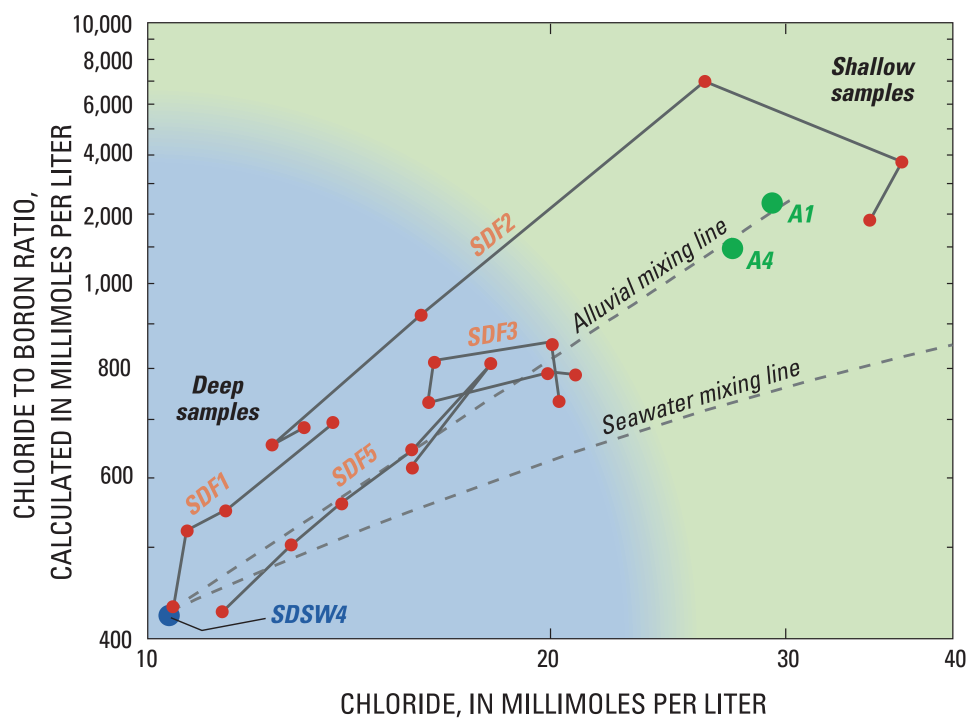

Figure 6. Differences in water quality with depth are illustrated by chloride-boron ratios. Water from shallow wells (A1 and A4) and deep well (SDSW4) form chemical end members that define an alluvial mixing line. Water from municipal supply wells (SDF1, 2, 3, and 5) falls generally along this mixing line with shallower samples having progressively more alluvial water. Chloride-boron ratios also illustrate that despite having a high concentration of dissolved solids, shallow samples do not fall along a seawater mixing line, and therefore do not contain recent seawater.

Table 1. Characteristics of sampled wells.

[All values are for composite water samples collected from well discharge; dissolved solids estimated from specific conductance; mg/L, milligrams per liter; nc, not collected; <, less than. Percentage of shallow water is calculated from vertical inflow data]

Characteristic	Shallow wells		Deep well	Municipal supply wells			
Local number	**A1**	**A4**	**SDSW4**	**SDF1**	**SDF2**	**SDF3**	**SDF5**
State well number	17S/2W–27R1	17S/2W–35E1	18S/2W–10C1	17S/2W–28R1	17S/2W–27N2	17S/2W–27P1	17S/2W–34C1
Dissolved solids, estimated, mg/L	2,560	2,420	1,440	2,010	2,850	1,870	1,470
Chloride, mg/L	1,040	969	368	488	1,230	720	558
Boron, mg/L	0.258	0.271	0.267	0.216	0.320	0.300	0.277
Tritium, picocuries/L	5.82	6.05	nc	non-detect	1.51	3.00	2.80
Carbon 13/12 ratio	nc	nc	–15.79	–14.75	–11.19	–13.90	–13.15
Age, in years	<50	<50	16,300	13,700	2,400	1,000	1,370
Shallow water, percent of total discharge	100	100	0	0	47	65	20

Age Dating

Analyzing tritium and carbon-14 in water can indicate the age of water (Clark and Fritz, 1997). Table 1 shows that water collected from the shallow wells is less than 50 years old. Water collected from the deep well is about 16,000 years old. These major differences in age can be used to analyze composite water samples collected from the discharge point of the municipal supply wells. The age of the composite sample depends on the relative contributions from shallow and deep ground water. The younger the apparent age of the composite sample, the greater the percentage of water contributed to the municipal well from shallow alluvial deposits.

The presence of tritium and the carbon-14 age support findings from the flowmetering that as much as 65 percent of the water from three municipal wells (SDF2, SDF3, and SDF5) comes from the shallow alluvial deposits. Water from municipal well SDF1 had no detectable tritium and a carbon-14 age of more than 13,000 years, indicating a deeper source.

Discussion

Three independent techniques were used to determine the vertical distribution of water extracted from four municipal supply wells. The three techniques—flowmetering, chloride-boron ratios, and age dating—confirm that two municipal supply wells (SDF2 and SDF3), despite being named for the San Diego Formation (SDF), extract about one-half of their water from alluvial deposits overlying the San Diego Formation. One municipal well (SDF1) extracts ground water solely from the San Diego Formation.

The source of water to supply wells is important for two reasons. First, recent water less than 50 years old is more likely to have anthropogenic contamination. Additional monitoring or treatment may be warranted prior to distributing pumped water for use. Second, water less than 50 years old pumped from relatively shallow alluvial deposits is likely to be a renewable resource.

In contrast, deeper, older ground water found in the San Diego Formation was recharged thousands of years ago, is less likely to have recent contamination, and may not be replenished as readily as ground water in the overlying alluvial deposits.

References

Boyle Engineering Corporation, 1994, Groundwater studies of the San Diego Formation: prepared for the Sweetwater Authority, 41 p.

Boyle Engineering Corporation, 1999, Aquifer storage and recovery project: San Diego Formation, phase 1 technical report: prepared for the San Diego County Water Authority [variously paged].

California Division of Mines and Geology, 2001, Geology of the San Diego metropolitan area, California: Bulletin 200 (reprinted), 55 p.

Clark, I.D., and Fritz, Peter, 1997, Environmental isotopes in hydrogeology: Lewis Publishers, 352 p.

Izbicki, J.A., Christensen, A.H., and Hanson, R.T., 1999, U.S. Geological Survey combined well-bore flow and depth-dependent water sampler: U.S. Geological Survey Fact Sheet 196–99, 2 p.

URS Greiner Woodward Clyde, 2000, Summary data report Lower Sweetwater Basin groundwater demineralization facility ground water wells, National City, California: prepared for the Sweetwater Authority [variously paged].

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